eMosaic: Electrification Mosaic Platform for Grid-Informed Smart Charging Management

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ABB Inc.

06/23/2022

ELT274

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Overview

Timeline

- Project start date: 10/2020
- Project end date: 12/2024
- Percent complete: 30%

Barriers

- Determine methods to integrate with Utility signals and management
- Provide a combined view of multiple charging sites, levels, and types to form a full picture of EV charging
- High level of interoperability desired
- Provide pilot demonstrations with scalability assessment

Budget

- Total project funding
  - Total: $7.6 M
  - DOE share: $4.93 M
  - Cost share: $2.73 M (20%)

Partners

INL: EV charge and operation modeling scalability and power HIL tests for demonstration, Timothy Pennington (lead)

Utah State University: EV charging site and transportation system modeling, EV site deployment, Regan Zane (lead)

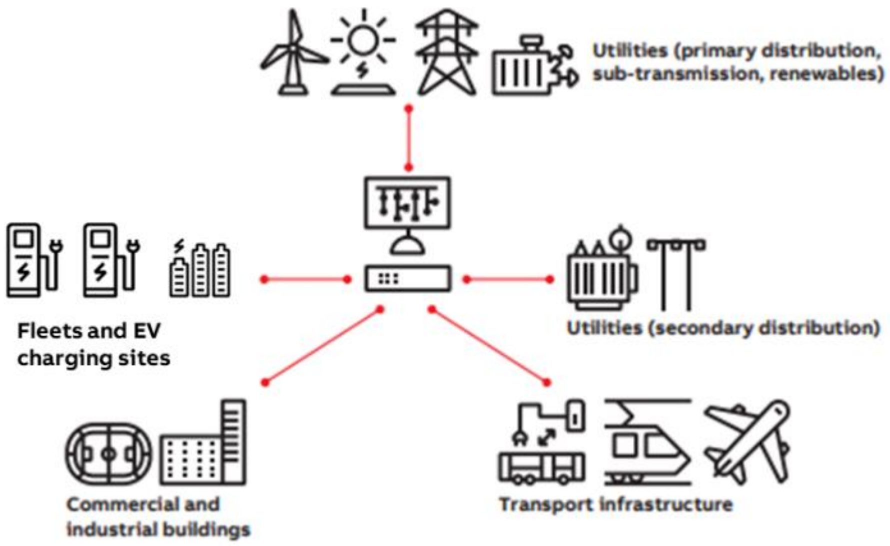
Rocky Mountain Power: Utility pilot planning and consulting, James Campbell (lead)

Proterra: EV transportation route planning consultation and telematics data for modeling and forecasting tasks, Alan Westenskow (lead)

Relevance

Provide a combined view of multiple charging sites, levels, and types to form a full picture of EV charging for Utility informed smart charging management:

- Use secure, interoperable communication protocols for real time measurement gathering (*EV Space:* OCPP, OpenADR; *Utility Space:* OPC-UA, DNP3, Modbus; *Cloud:* AMQP, REST and other APIs)
- Explore site level control strategies to utilize utility planning, forecasting, and available resources to inform pricing and incentives such as transportation route planning or fleet logistics
- Determine smart charging management needs for cloud aggregation and management features
- Enable larger scale grid services beyond individual sites informed by utility needs and input



Objectives:

- Develop a scalable, secure, and resilient eMosaic (local+cloud) platform to provide localized and bulk grid services and smart charge management (load or congestion management, load forecasting, dynamic reservations).
- Field deploy, validate and demonstrate controllers and cloud platform in the Rocky Mountain Power/PacifiCorp service territory
- Research, develop, and demonstrate a reference EV charging aggregation and control to provide novel features to utilities

Approach

Milestones

No.	Milestones for BP1 and BP2	Date
M1	Complete Edge/cloud platform architecture design	6/30/2021
M2	Complete site requirement evaluation and initial data collection	6/30/2021
M3	Complete Caldera data simulation and model development	9/30/2021
M4	Complete data model and grid service algorithm design	9/30/2021
M5/M6	Complete eMosaic SCM function development prototype, and demo charging site control	11/30/2021
M7	Go/No Go	12/31/2021
M8	Complete laboratory test design	3/31/2022
M9	Preliminary laboratory tests for site integration	6/30/2022
M10/11	Final laboratory test for site integration/Field deployment and demonstration plan	9/30/2022
M12	Go/No Go	10/31/2022

No.	Milestones for BP3 and BP4*	Date
M13	Preliminary field deployment planning	1/30/2023
M14	Final field deployment planning	4/30/2023
M15	Field functionality test	9/30/2023
M16	Go/No Go	10/31/2023
M17	Preliminary scalability test	3/31/2024
M18	Final scalability test	6/30/2024
M19	Final demonstration and performance improvement	12/30/2024
Knowledge and Technology Transfer		

*Any proposed future work is subject to change based on funding levels.

ABB

Approach

Detailed Tasks for eMosaic Project Budget Period 1-2 (Year 1-2)

- **Task 1.1: eMosaic Architecture Design – Completed**
- **Task 1.2: Grid Service Development – Completed**
- **Task 1.3: Model and Control Design of Charging Sites – Completed**
- **Task 2.1: Initial eMosaic Platform Setup/Test – In Progress**

  Task 2.1.1: Facility preparation

  Task 2.1.2: Test connectivity for edge to cloud at multiple sites

  Task 2.1.3: Component level test including function and cybersecurity test

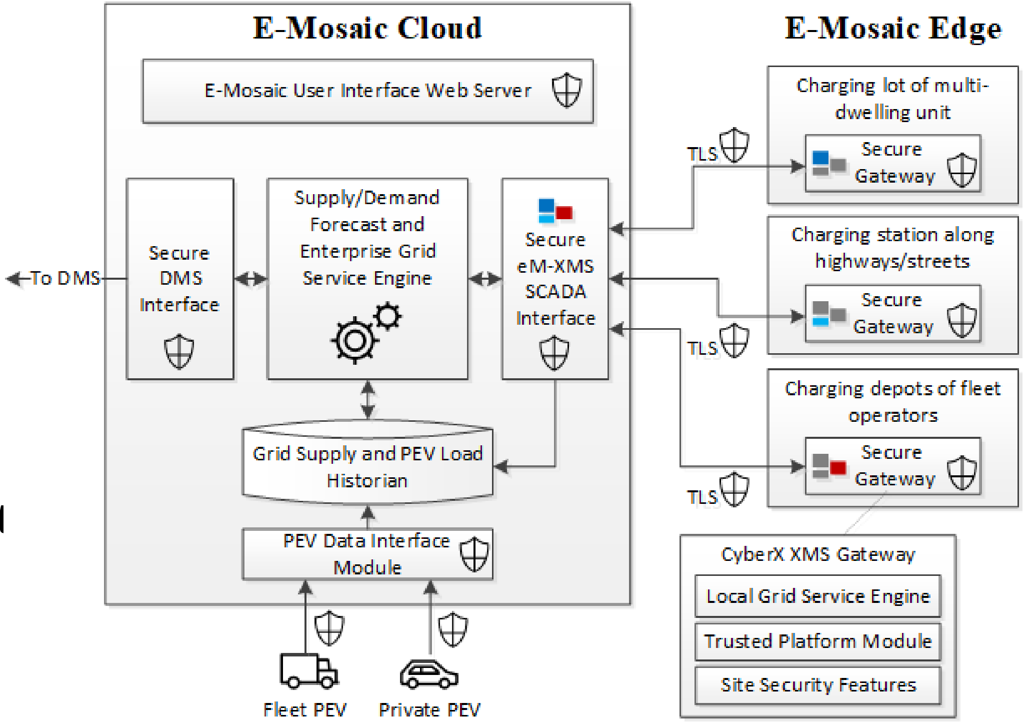
  Task 2.1.4: System level test integrate sites with local and cloud control
- **Task 2.2: eMosaic Platform Demo Planning**

  Task 2.2.1: Scalability and interoperability planning

  Task 2.2.2: Commissioning requirements definition

  Task 2.2.3: Data collection requirements

  Task 2.2.4: Performance matrix definition



Approach

Detailed Tasks for eMosaic Project Budget Period 3-4 (Year 3 - 4)

Task 3.1: Charging Site Installation, Connectivity Validation, and Test Scenario Definition

Task 3.1.1: Installation & device commission

Task 3.1.2: Cybersecurity design review

Task 3.1.3: Communication connection and interoperability demonstration

Task 3.1.4: Test scenario definition

Task 3.1.5: Provide EV and supply interoperability requirements

- **Task 3.2: System Functionality Test**

  Task 3.2.1 - .2: Local/Cloud Grid Service Functionality

- **Task 4.1: System Scalability Test**

  Task 4.1.1 - .2: Simulation Scale-up for Individual Site and Service Territory

- **Task 4.2: System Real-Time Performance Test**
- **Task 4.3: Knowledge and Technology Transfer**

Unique aspects - *(1) Edge and cloud enabled features for smart aggregate and grid service (2) Reinforcement learning based charging site control (3) Location dependent multi-category demand/price forecast (4) Pilot using real hardware and scaled co-simulation*

Approach

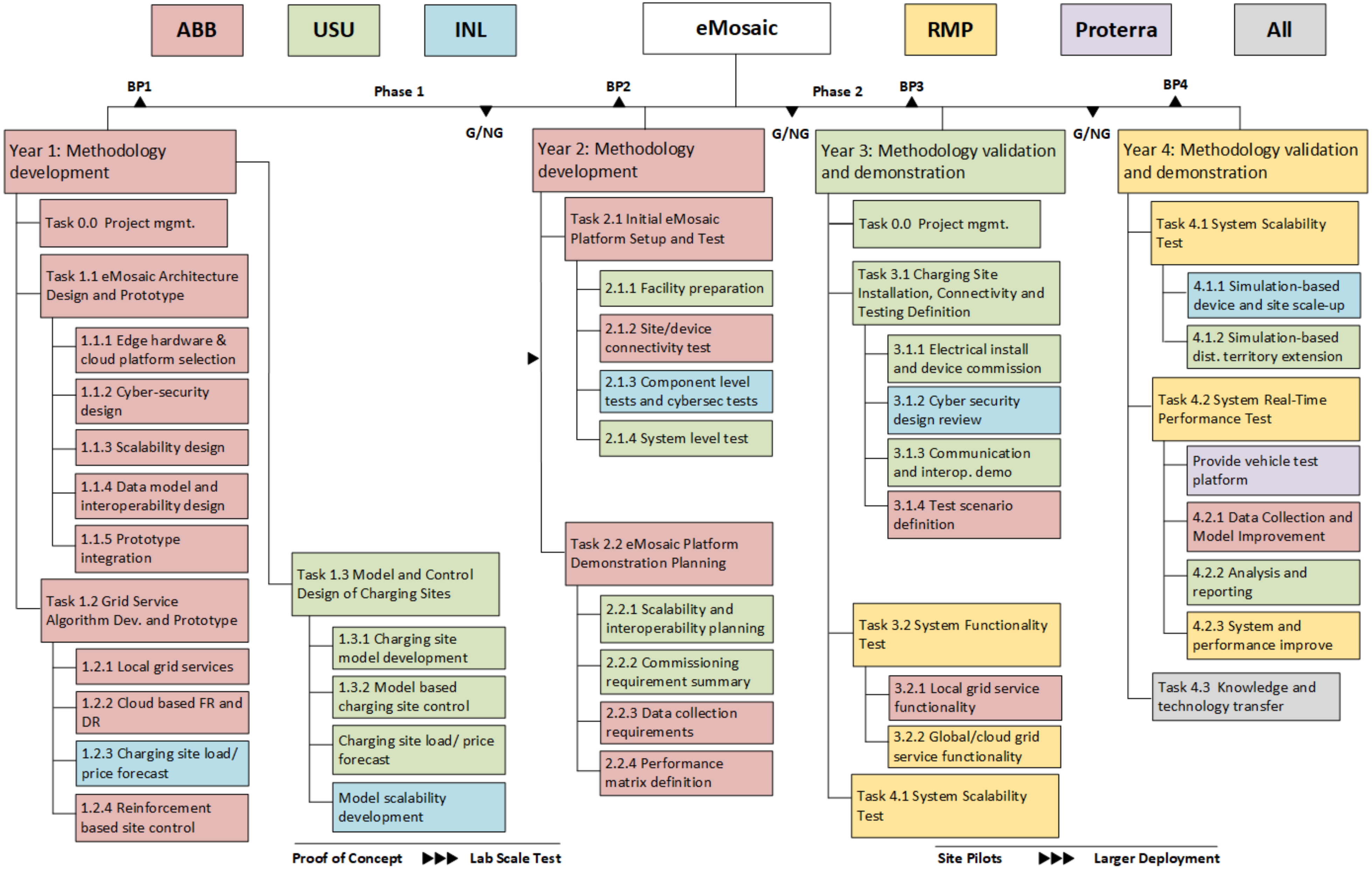


ABB
USU
INL
eMosaic
RMP
Proterra
All
BP1
Phase 1
G/NG
BP2
G/NG
Phase 2
BP3
G/NG
BP4
Year 1: Methodology development
Task 0.0 Project mgmt.
Task 1.1 eMosaic Architecture Design and Prototype
1.1.1 Edge hardware & cloud platform selection
1.1.2 Cyber-security design
1.1.3 Scalability design
1.1.4 Data model and interoperability design
1.1.5 Prototype integration
Task 1.2 Grid Service Algorithm Dev. and Prototype
1.2.1 Local grid services
1.2.2 Cloud based FR and DR
1.2.3 Charging site load/ price forecast
1.2.4 Reinforcement based site control
Task 1.3 Model and Control Design of Charging Sites
1.3.1 Charging site model development
1.3.2 Model based charging site control
Charging site load/ price forecast
Model scalability development
Year 2: Methodology development
Task 2.1 Initial eMosaic Platform Setup and Test
2.1.1 Facility preparation
2.1.2 Site/device connectivity test
2.1.3 Component level tests and cybersec tests
2.1.4 System level test
Task 2.2 eMosaic Platform Demonstration Planning
2.2.1 Scalability and interoperability planning
2.2.2 Commissioning requirement summary
2.2.3 Data collection requirements
2.2.4 Performance matrix definition
Year 3: Methodology validation and demonstration
Task 0.0 Project mgmt.
Task 3.1 Charging Site Installation, Connectivity and Testing Definition
3.1.1 Electrical install and device commission
3.1.2 Cyber security design review
3.1.3 Communication and interop. demo
3.1.4 Test scenario definition
Task 3.2 System Functionality Test
3.2.1 Local grid service functionality
3.2.2 Global/cloud grid service functionality
Task 4.1 System Scalability Test
Year 4: Methodology validation and demonstration
Task 4.1 System Scalability Test
4.1.1 Simulation-based device and site scale-up
4.1.2 Simulation-based dist. territory extension
Task 4.2 System Real-Time Performance Test
Provide vehicle test platform
4.2.1 Data Collection and Model Improvement
4.2.2 Analysis and reporting
4.2.3 System and performance improve
Task 4.3 Knowledge and technology transfer
Proof of Concept ▶▶▶ Lab Scale Test
Site Pilots ▶▶▶ Larger Deployment

Technical Accomplishments to Date

Task Info	Tracking Metric	Goal for Period	Accomplishments	Completion	
				Expected	Actual
Edge/Cloud Platform Architecture (M1)	eMosaic SW architecture designed and prototyped for edge solution	Edge hardware platform and targeted cloud connectivity features selected	(1) Selected cloud services and containerized key edge/cloud software (2) Determined key external interfaces and methods to secure each (3) Determined and demoed interoperable protocols and modeling of necessary data	Milestone 1 3/30/2021	Milestone 1 7/30/2021
Site Requirement and Initial Data Collection (M2)	Model and control design of charging sites	Gather initial charging site data and develop charging site model for control	(1) Identified loads across selected distribution network and collected data to inform reqs. and model (2) Developed distribution network model and derived control strategies	Milestone 2 6/30/2021	Milestone 2 11/30/2021
Caldera Simulation & Model Dev. (M3)	Charging site load/price forecast	Gather initial charging site data and develop charging site model for control	(1) Caldera produces charging site load based on initial demand data. Used extensively by ABB for control verification activities (2) Caldera implements several charging controls that impact site load.	Milestone 3 11/30/2021	Milestone 3 1/30/2022

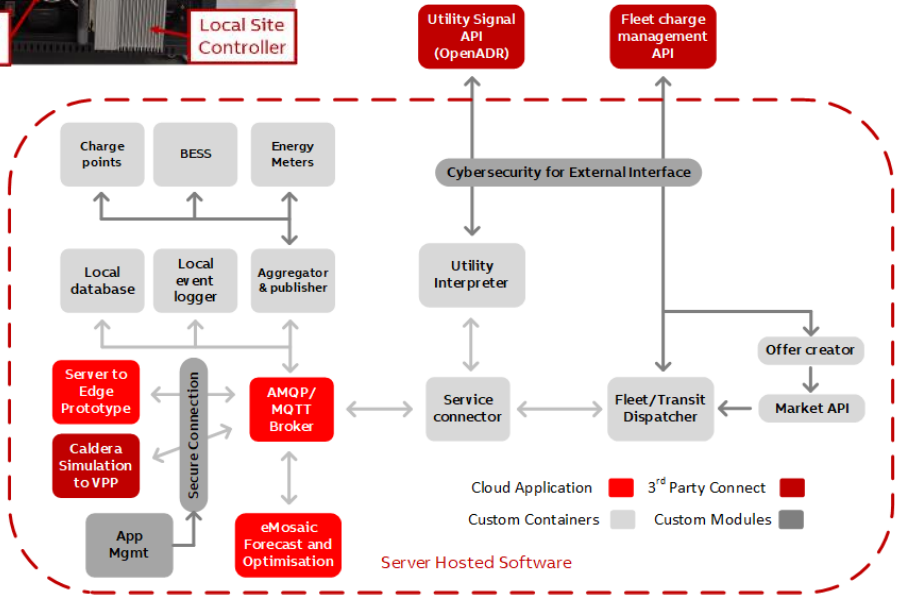
Technical Accomplishments to Date

Task Info	Tracking Metric	Goal for Period	Accomplishments	Completion	
				Expected	Actual
Data model and grid service algorithm design (M4)	Grid service process development	Two or more local grid services formulated for the secure gateway	(1) Peak load shedding and grid voltage support algorithms verified through modeling work. (2) OpenADR capability demonstrated for DR and example implementation of frequency regulation for AC chargers	Milestone 4 11/30/2021	Milestone 4 11/30/2021
Demo charging site control design (M5)	Deploy and test cyber security algorithms in XFC station Cyber Physical Test Bed	Utilize simulation data to provide charging site forecast function	(1) Develop site control model and calibrate model with historical and real-time load information and pricing (2) Evaluate load/rate impacts for site with control model implemented	Milestone 5 11/30/2021	Milestone 5 12/31/2021
eMosaic smart charging function dev & prototype (M6/7)	eMosaic software architecture designed and prototyped for cloud solution	Platform for cloud services selected and software architecture prototype demoed	(1) A methodology for charging site load prediction has been developed and implemented. (2) grid-informed pricing has been implemented in an example system	Milestone 6 11/30/2021 Go/No-Go 11/30/2021	Milestone 6 11/30/2021 Go/No-Go 12/30/2021
Laboratory test design (M8)	Initial eMosaic platform setup and testing	Integrated algorithms and HIL testbed for virtual + physical charger tests planned for 3 sites	(1) Integration of platforms and modeling tools – Caldera, OpenDSS, Typhoon HIL, eMosaic edge (2) Design of partner site communication configurations	Milestone 8 3/31/2022	Milestone 8 3/31/2022

Technical Accomplishments to Date

Milestone 1: Edge/cloud platform architecture design

- Selected initial hardware and cloud platforms for technology development
- Setup on-premise server/cloud for developing reinforcement learning, forecasting, and grid service algorithm development
- Designed initial plans for scalability of site solutions including multi-factored containerized applications running at individual sites or on higher performance server
- Selected initial hardware and cloud platforms for technology development
- Testing site control strategies using modeled data from INL's Caldera tools



Initial hardware and cloud platforms for technology development selected to enable aggregation and control

Technical Accomplishments to Date

Milestone 2: Site requirement evaluation and modeling

Graphical Model for Smart Charging and Peak Demand Management

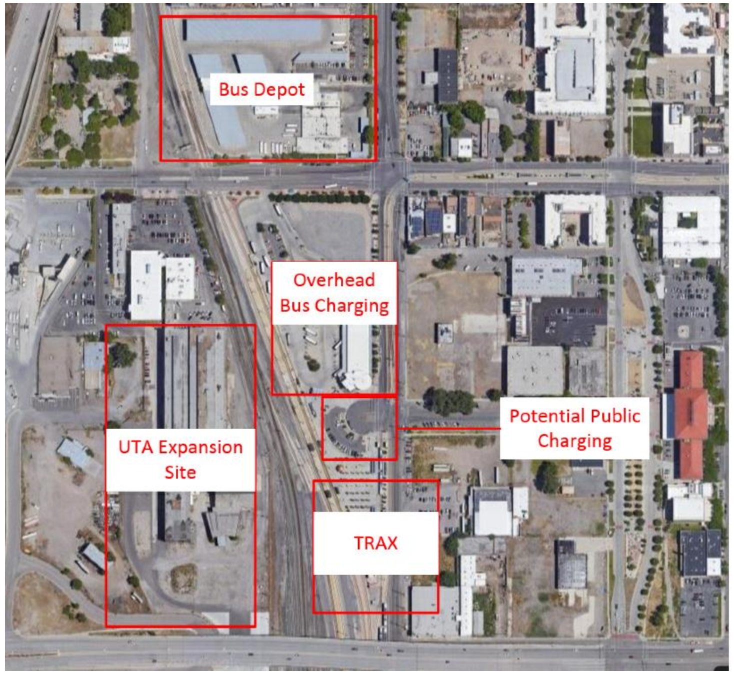
- Determine optimal bus charging schedule
- Minimize energy consumption and time-of-day dependent peak average power weighted by contributions to monthly bill
- Plan for time-varying uncontrolled loads (TRAX – light rail, CNG fueling station, snowmelt, etc.)
- Account for UTA route times/constraints

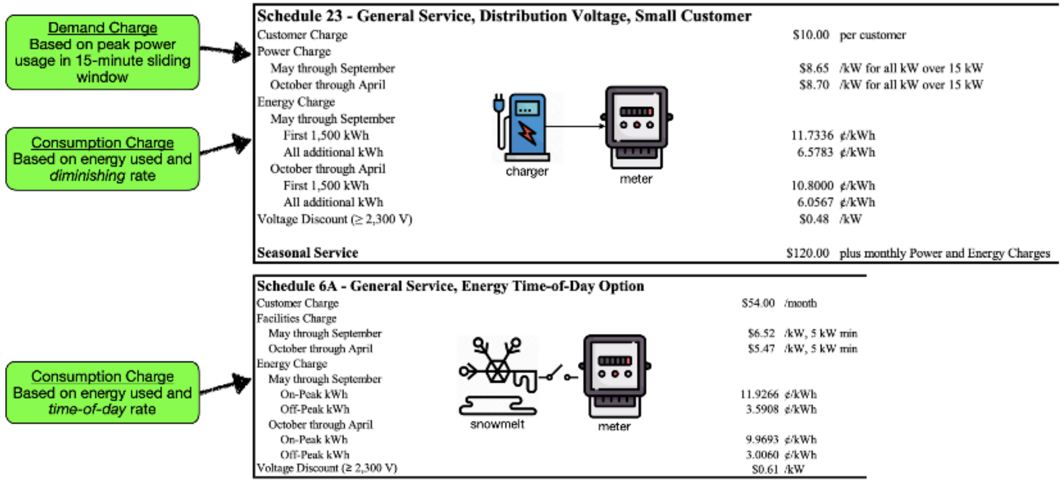
Required inputs

- Real-time measurements of uncontrolled loads (TRAX, CNG fueling, etc.)
- Real-time bus location and SOC (UTA + bus OEM APIs)
- Dynamic model for battery charging
- Model for battery route-discharge (calibrated from historical data)
- UTA route schedules
- Communication with chargers (OCPP – USU developed server)

Future extensions

- Multiple interacting charge sites (system-level planning)
- Re-plan light rail schedules to reduce peak demand (joint optimization)
- Charge public (random) and other fleet vehicles (scheduled)
- Communicate with EV operators to schedule arrivals in space/time





Schedule 23 - General Service, Distribution Voltage, Small Customer		
Customer Charge	$10.00	per customer
Power Charge		
May through September	$8.65	/kW for all kW over 15 kW
October through April	$8.70	/kW for all kW over 15 kW
Energy Charge		
May through September		
First 1,500 kWh	11.7336	¢/kWh
All additional kWh	6.5783	¢/kWh
October through April		
First 1,500 kWh	10.8000	¢/kWh
All additional kWh	6.0567	¢/kWh
Voltage Discount (≥ 2,300 V)	$0.48	/kW
Seasonal Service	$120.00	plus monthly Power and Energy Charges

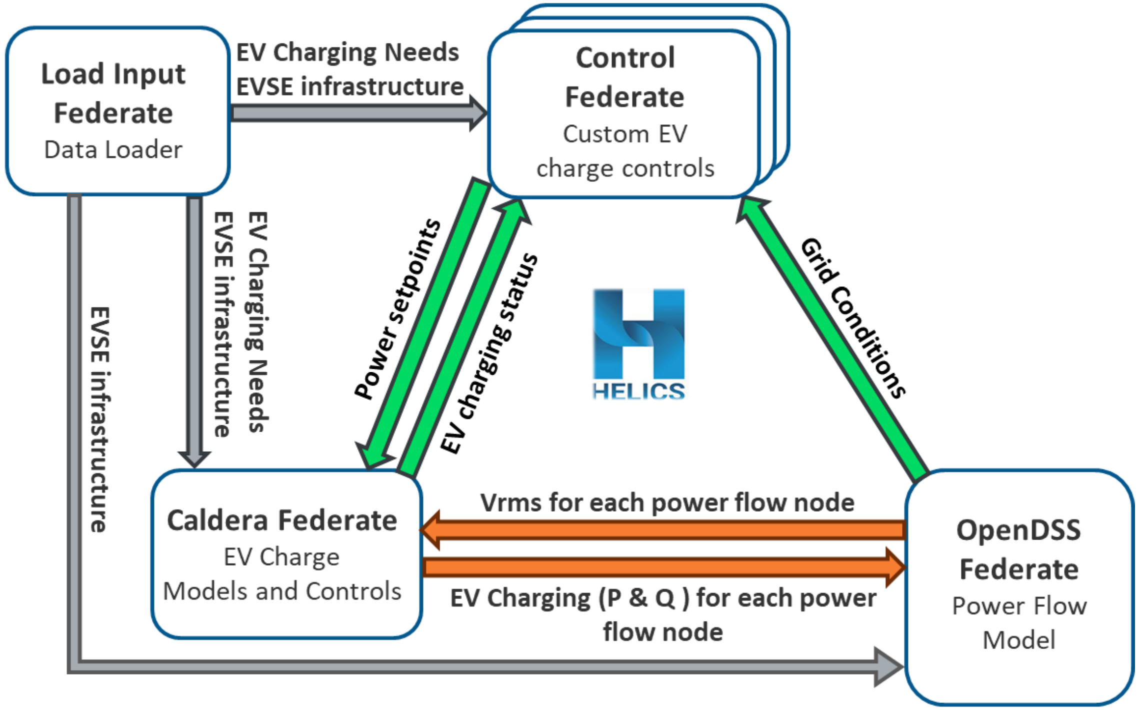
Schedule 6A - General Service, Energy Time-of-Day Option		
Customer Charge	$54.00	/month
Facilities Charge		
May through September	$6.52	/kW, 5 kW min
October through April	$5.47	/kW, 5 kW min
Energy Charge		
May through September		
On-Peak kWh	11.9266	¢/kWh
Off-Peak kWh	3.5908	¢/kWh
October through April		
On-Peak kWh	9.9693	¢/kWh
Off-Peak kWh	3.0060	¢/kWh
Voltage Discount (≥ 2,300 V)	$0.61	/kW

Defining EV charging site modeling requirements based on first identified Intermodal Hub Site

Technical Accomplishments to Date

Milestone 3: Caldera data simulation and model development

- Implemented 2 types of control framework to integrate smart charge management (SCM) into Caldera co-simulation platform.
  - Loosely coupled control (intermittent communication)
  - Tightly coupled control (granular periodic communication)
- Upgraded the co-simulation framework from HELICS* 2 to HELICS 3.
- Removed the limitation on amount of data passed between HELICS federates in the Caldera co-simulation platform.
- ABB and USU implemented control strategies to simulate EVSE behavior at charging sites (controls to govern multi-outlet chargers, charging rate and output control, and smart charging limits) using Caldera



Caldera co-simulation platform architecture

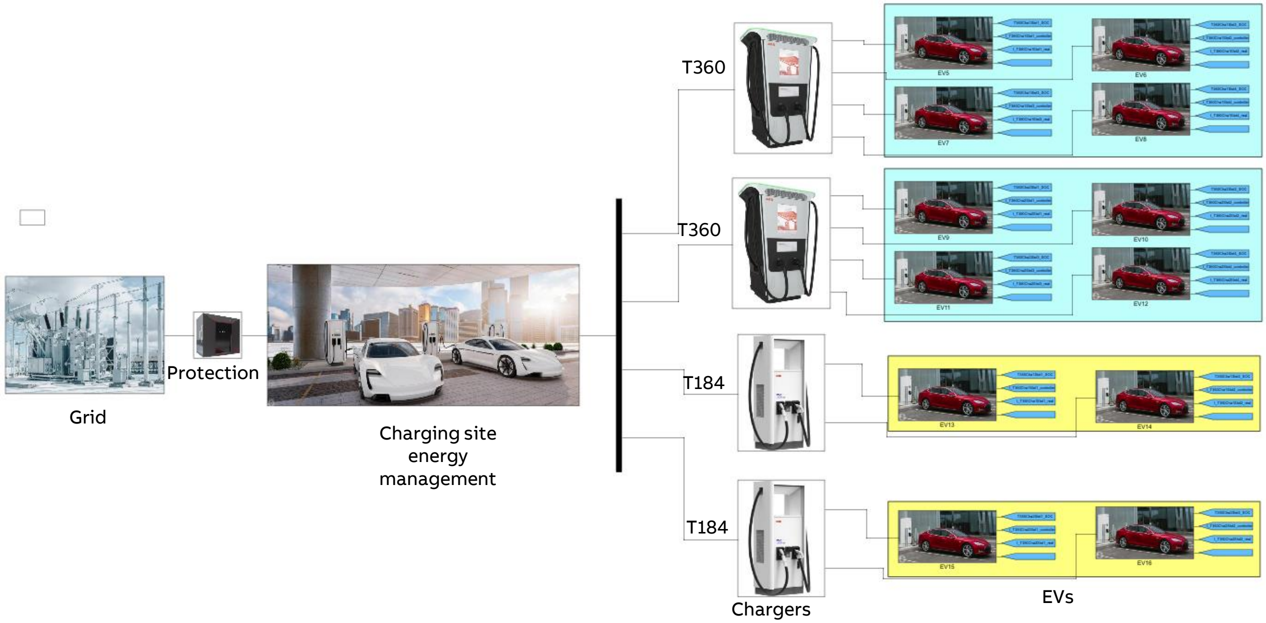
Modeling tools used for prototyping site control features and planning future system scalability

*Hierarchical Engine for Large-scale Infrastructure Co-Simulation (HELICS) allows for integration with other simulation and co-simulation platforms

Technical Accomplishments to Date

Milestone 4: Data model and grid service algorithm design report complete

- Charging session data-based site load prediction algorithm has been developed.
- Past data is used to predict site load behavior patterns, while more recent data is used to scale the behavior patterns, to predict day-ahead load profiles at EV charging sites.
- A synthetic environment to help train an RL agent to set the price of charging at different sites to influence user behavior has been developed.
- The solution is designed to help reduce the cost of delivering power to the customer, while also assisting the grid/utility.

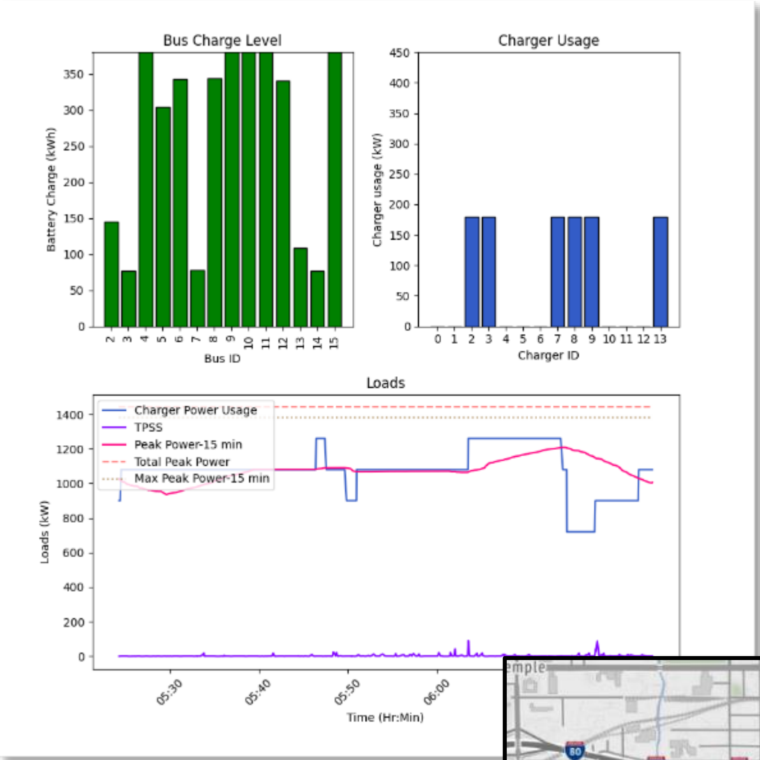


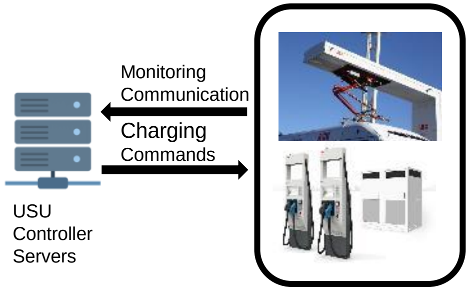
Defining algorithms and required models and data to develop proposed features

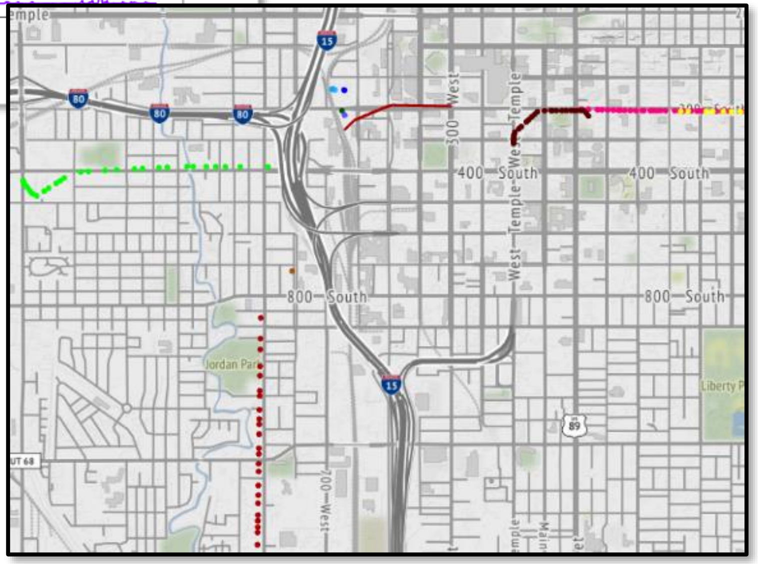
Technical Accomplishments to Date

Milestone 5: Demonstration charging site control design

- Identified and collected data from loads across site's distribution network
- Developed architecture for rapid prototyping of battery electric bus charger scheduling
- Framework permits a live, virtual, constructive development environment
  - Live: run system with actual bus information
  - Virtual: run system with simulated / recorded data
  - Constructive: Combine live and virtual components
  - Built upon the Robot Operating System (ROS) , a Linux-based software with a modular pub/sub architecture and ecosystem of tools for test and development
- Interfaced with real-time data for planning and monitoring
  - Live bus information received through the UTA and bus OEM APIs
  - Light rail data received through custom web-socket interface to sub-station



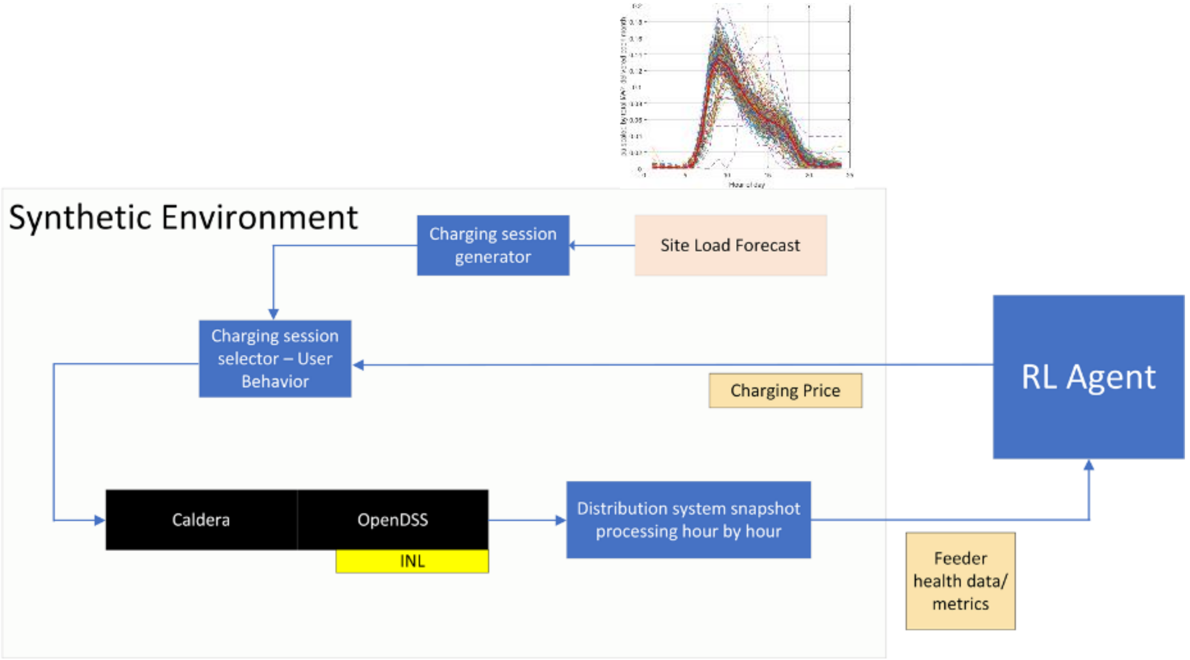




Technical Accomplishments to Date

Milestone 6: eMosaic smart charging function dev & prototype

- The RL agent is trained in a synthetic environment to set the price of charging, based on real-time feeder health metrics.
- Trained agent can start will be the starting point in the demo – the agent will also learn from the real world once deployed
- The Synthetic Environment involves
  - Realistic EV charging sessions modeled by Caldera [INL]
  - IEEE 34 bus simulation to gauge the impact of EV load, in OpenDSS [INL]
  - A charging session generator, that generates charging sessions based on the day-ahead site load forecast
  - A charging session selector, that models the user's behavioral response to the price of charging



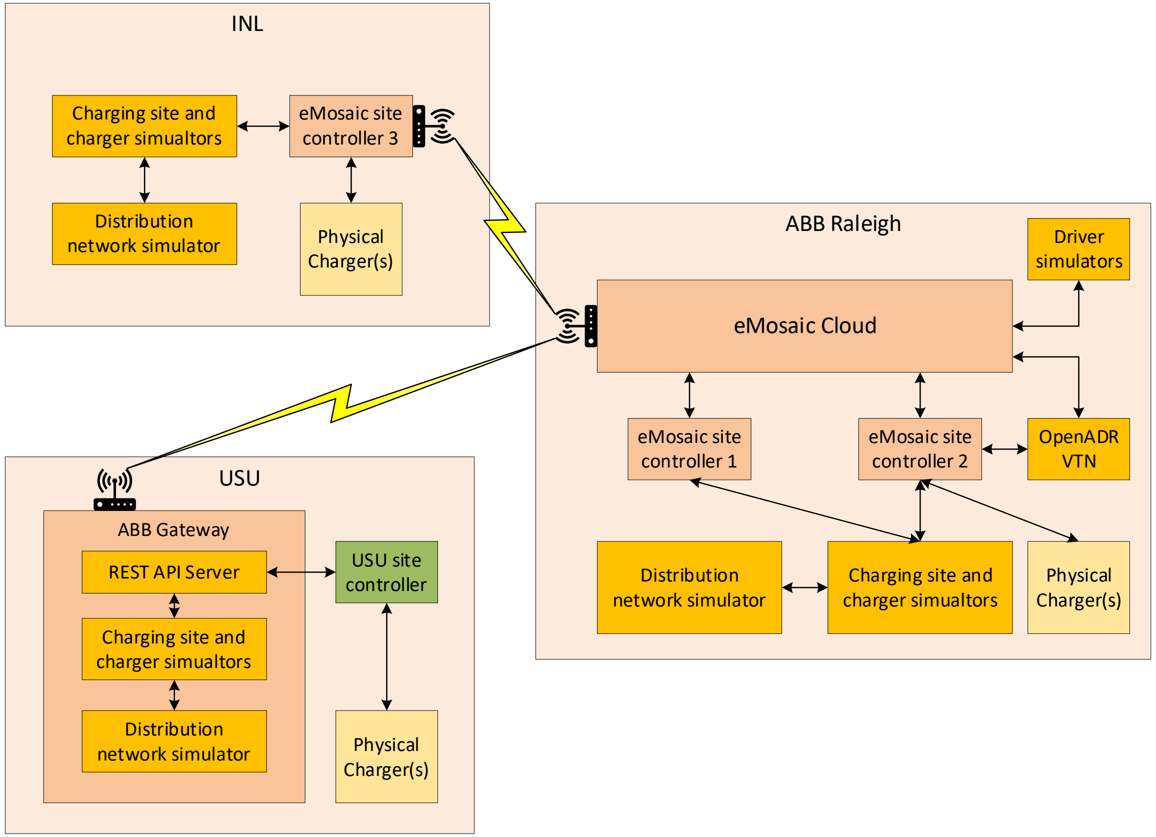
Completed Milestone 7 Go/No-Go Decision with decision to continue to BP2

ABB

Technical Accomplishments to Date

Milestone 8: Laboratory Test Design

- Protocols defined for different communication channels
  - OPC UA between site system components (e.g. charger to site controller)
  - Secure REST between parties (e.g. ABB to USU controllers)
  - AMQP over VPN across geography
- Network model development
  - OpenDSS distribution network model with diversity in number/types for chargers different charging site use cases
  - IEEE 34-bus model can be replaced with real site system model
- Hardware deployment planning at partner test sites is underway



Testing configurations and site communications designs

Responses to Previous Year Reviewers' Comments

- *Reviewer comment:* The cybersecurity design review should be accomplished earlier in the program because if there is a poor cyber design, then that will either take much more time and/or resources to fix later in the project or will be ignored. // The reviewer was also concerned that cybersecurity and model are not identified for future work either The reviewer urged moving this forward and enshrining it in the project team's future work plans
  - Response: Cybersecurity review was planned as part of the laboratory testing, and a more dedicated cybersecurity review (ABB internal and external) will take place within budget period 2. Elements of cybersecurity testing were proposed within Budget Periods 1 and 2, but not as explicitly stated in the presentation material. This was corrected for AMR presentations this year.
- *Reviewer comment(s):* Are load predictions exclusively historically based, or are there dynamic needs-driven data being considered in projections? It seems a dynamic, needs driven component would be valuable.
  - Response: The goal is to be dynamic with a combination of real time measurement data, reservation type data, and more historic data at the site or multi-site level. Plans are in process to incorporate reservation systems, transportation schedules, and feedback from OpenADR or similar utility signals.
- *Reviewer comment:* [The project would benefit from including] EVSE manufacturers, a charge point operator, and more electric utility input. They will help with the goal of obtaining industry-wide acceptance of the project results.
  - Response: This is a great point and part of the goal of the project was to work through Utah State's network of ASPIRE partners for input and feedback. The team will seek more inputs to gain a broader perspective

Collaboration and Coordination

- **Project collaborators**
  - ABB (prime), industry vendor
  - INL (sub), national lab
  - Utah State University (sub), academic
  - Rocky Mountain Power (sub), utility
  - Proterra (sub), transportation sector

- **Communications**
  - Weekly meeting, ABB internal
  - Monthly to Bi-Monthly meeting, Project partners
  - As needed meeting with DOE and partners

- **ABB: EV site and cloud platforms for EV charging hardware integration and**
  - Integration of EV supply equipment, modeling and simulation for control feature
- **INL: EV modeling, EV Cybersecurity, and Power hardware-in-the-loop simulator for demonstration**
  - EV/EVSE modeling, HIL testbed and power systems
- **USU: Electric distribution system site control modeling and forecasting, EV equipment deployment**
  - EV/EVSE site modeling and forecast algorithms for control
- **RMP: EV pilot planning and deployment support**
  - EV engineering and demonstration support
- **Proterra: EV transportation route planning consultation and fleet scheduling interface support**

Remaining Challenges and Barriers

- Implementing integration of fleet or transportation dispatch management APIs
- Providing a security by design approach to embedded edge and remote cloud infrastructure for real-time aggregation and effective forecasting
- Validating feasibility of developed algorithms for reinforcement of price trends and user behavior incentives on price and other EV charging benefits to affect grid stability and planning
- Commissioning and coordinating pilot sites with additional controllers and data aggregations platforms
- Validating approach of scalability using Caldera modeling co-simulation and integrating with pilot sites to provide value

Proposed Future Works

- **Ongoing FY-22**
  - Set up an eMosaic local controller and cloud connection at USU and INL lab facilities for aggregation and feature testing
  - Plan a lab scale demonstration incorporating multiple sites and assess the eMosaic platform
  - Define interconnections for providing grid informed charging (protocols, models needed)
  - Define requirements for data gathering to support forecasting and other proposed control features
- **FY-23***
  - BP3: shift to demonstration phase
  - Implementation of technologies at Rocky Mountain Power sites

*Any proposed future work is subject to change based on funding levels.

Summary

Designing eMosaic platform to provide a combined view of multiple charging sites, levels, and types to form a full picture of EV charging for Utility informed smart charging management

Over-all on-time progress and completion of 8 milestones in progress:

Milestones in progress:

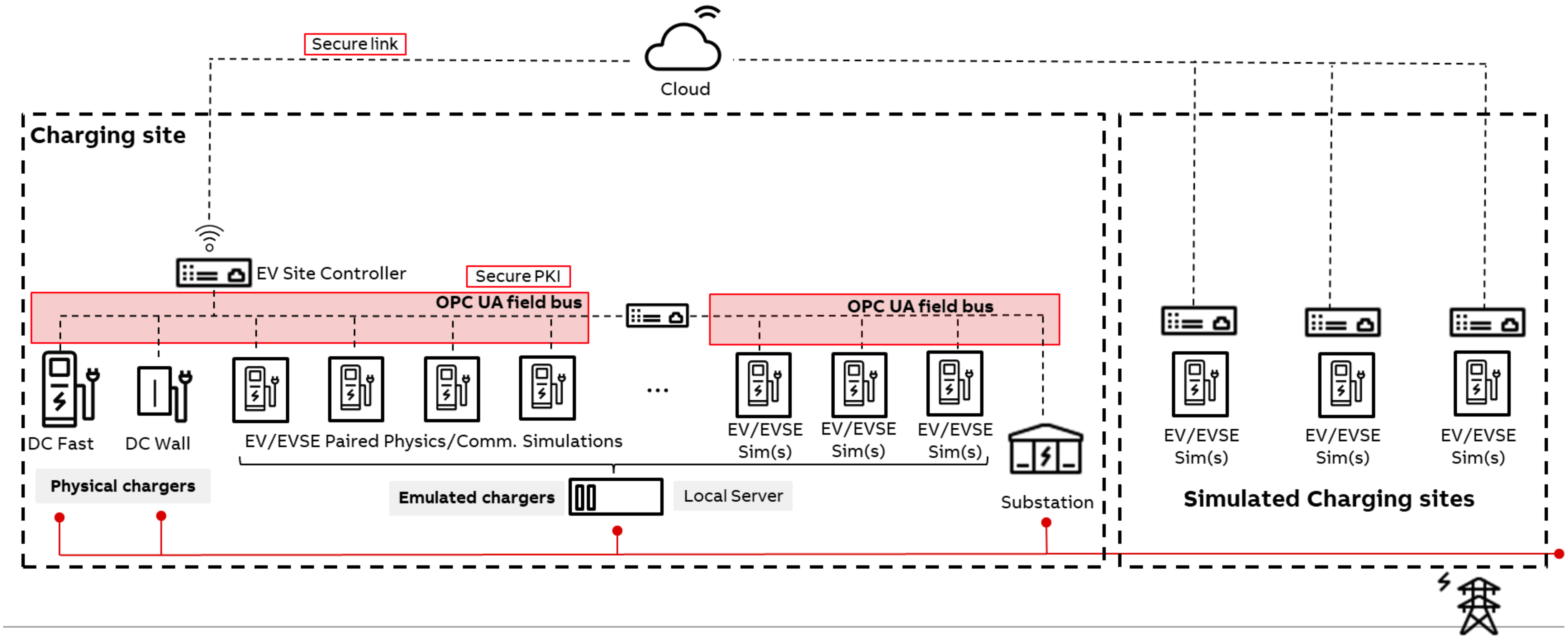
- Initial testing and preliminary laboratory results for site integration, started with planning at three laboratory sites
- Final laboratory test for site integration
- Commissioning plan for pilot demonstration

Field deployment and demonstration plan to be finalized in Q3 to prepare for successful demonstrations in BP3 and 4 at scale

*Any proposed future work is subject to change based on funding levels.

Technical Back-Up Slides

Detailed Test Configuration



USU Charger Communication Development

Current state of ABB Communication:

Established communications with local and remote chargers

– (T* IDs local, N* remote)

Current status data from meters are returning values

```
Charge Point ID (First Connect):  T175-IT1-3420-016
Charge Point ID (First Connect):  NAMHVC150-MX1-5118-005
Charge Point ID (First Connect):  T175-IT1-3420-003
```

Additional work is being done on the device side OCPP client to enable core features of OCPP:

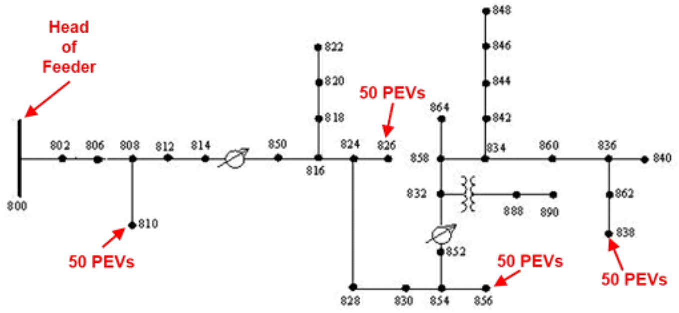
– Faster data acquisition

– Real-time meter power data and control

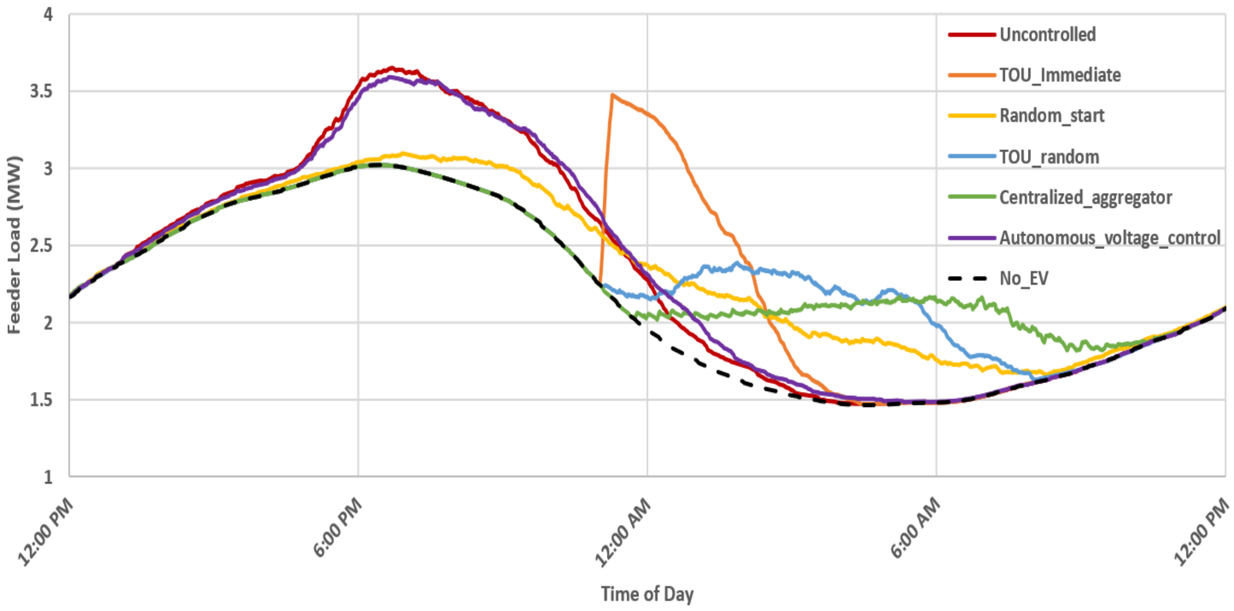

```
{'status': 'Available', 'timestamp': '2022-04-14T21:56:33.651Z'}
{'status': 'Available', 'timestamp': '2022-04-14T21:56:58.837Z'}
{'status': 'Available', 'timestamp': '2022-04-14T21:56:58.841Z'}
```

EV charge management strategies implement in Caldera

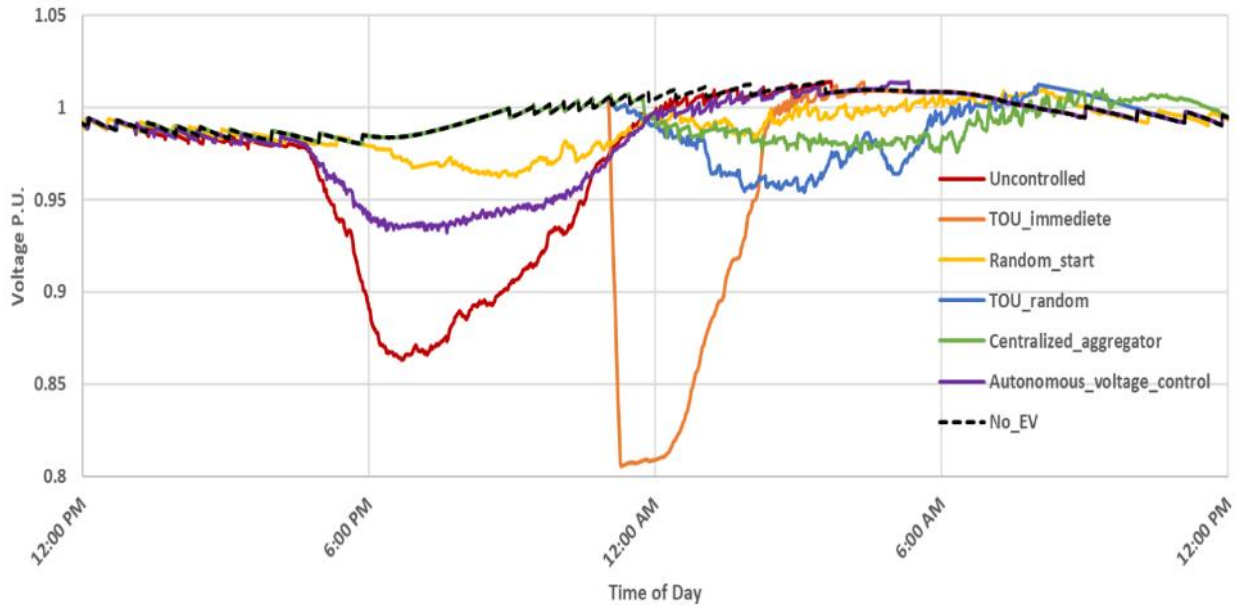
The load profiles illustrate the performance of various control strategies developed in Caldera and modelled on IEEE 34 node test feeder.



IEEE 34 Node Test Feeder



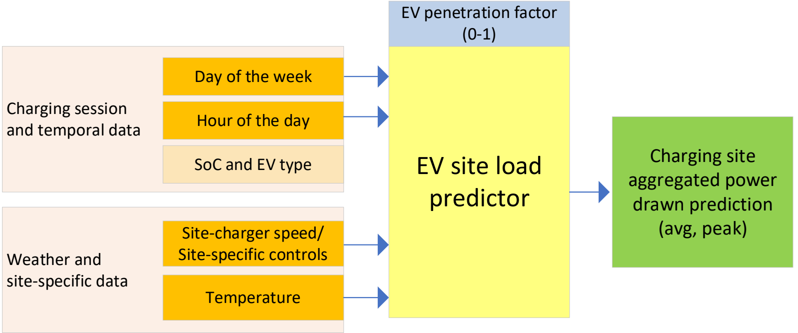
Feeder Load Profiles

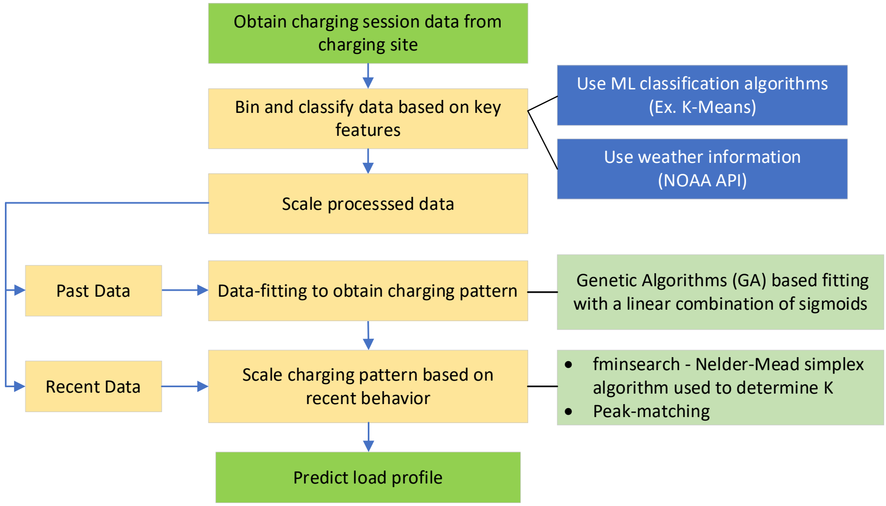


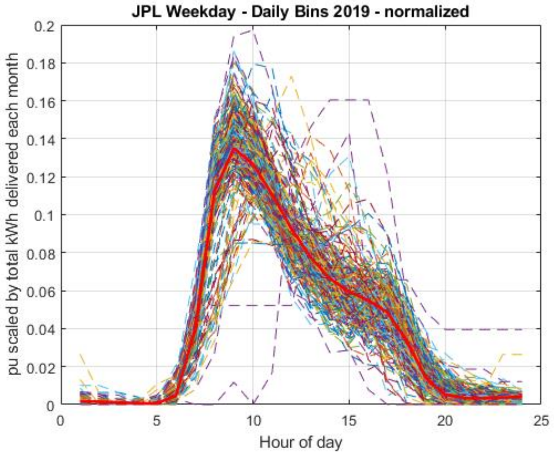
Voltage P.U. Profiles

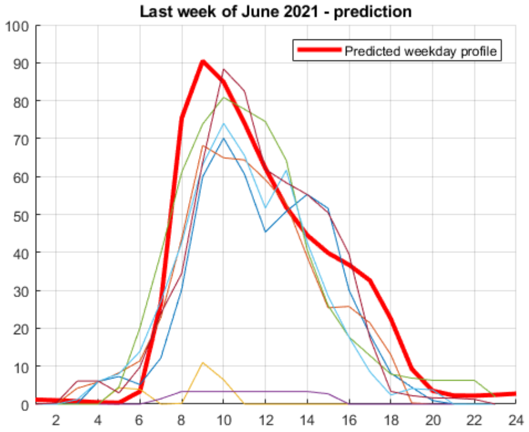
Milestone 6: eMosaic SCM function development & prototype

Completed, Tasks 1.2.3 and 1.2.4









Data source

- Thousands of charging sessions from 2019, 2020, and 2021 from CalTech's ACN network from two EV charging locations were used

Data-based prediction method developed

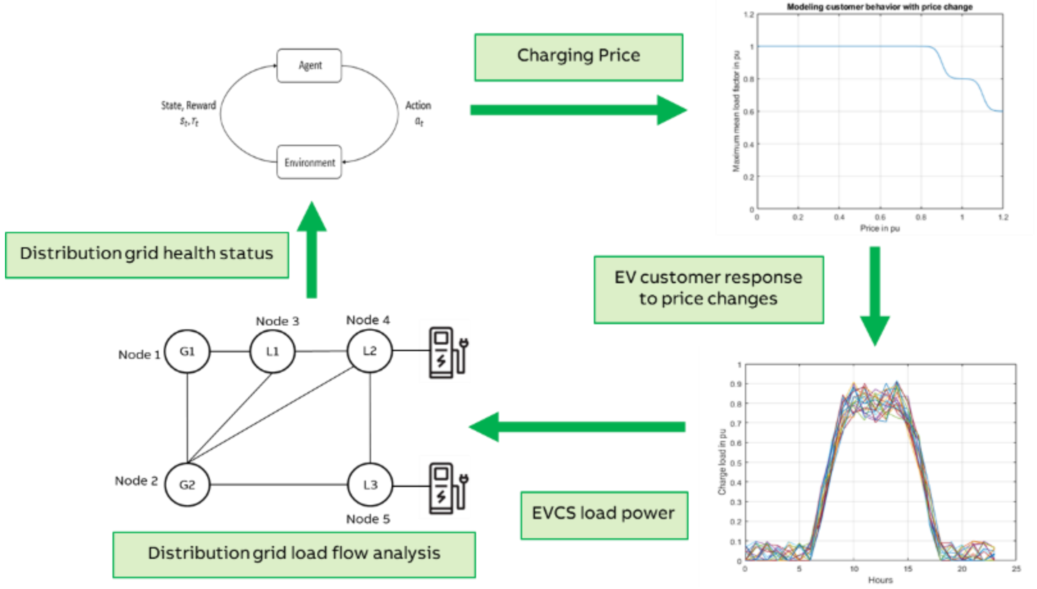
- Past data is used for capturing charging behavior and recent data is used to scale the behavior profile

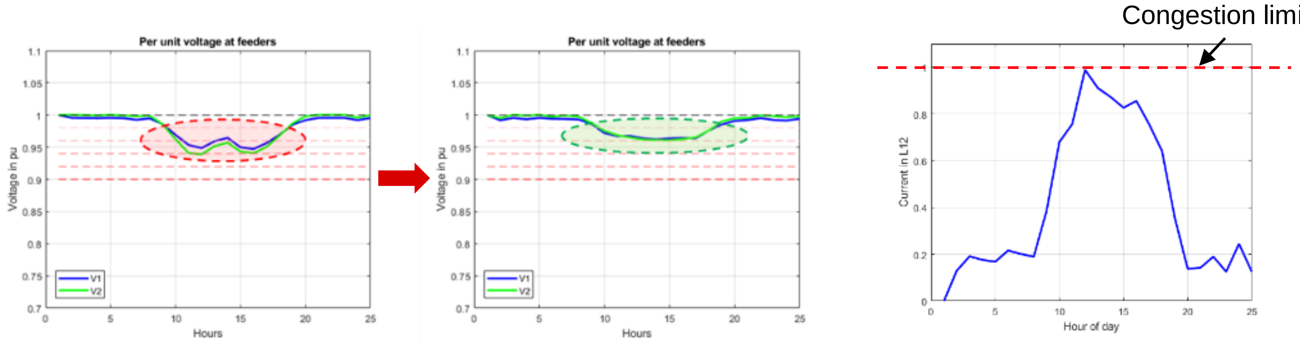
* Further efforts and studies to improve binning using charge profiles and match with power drawn from Caldera simulations is in progress

** Data from ABB owned sites was also gathered and considered

Milestone 6: eMosaic SCM function development & prototype

Completed, Tasks 1.2.3 and 1.2.4





Grid-informed charging

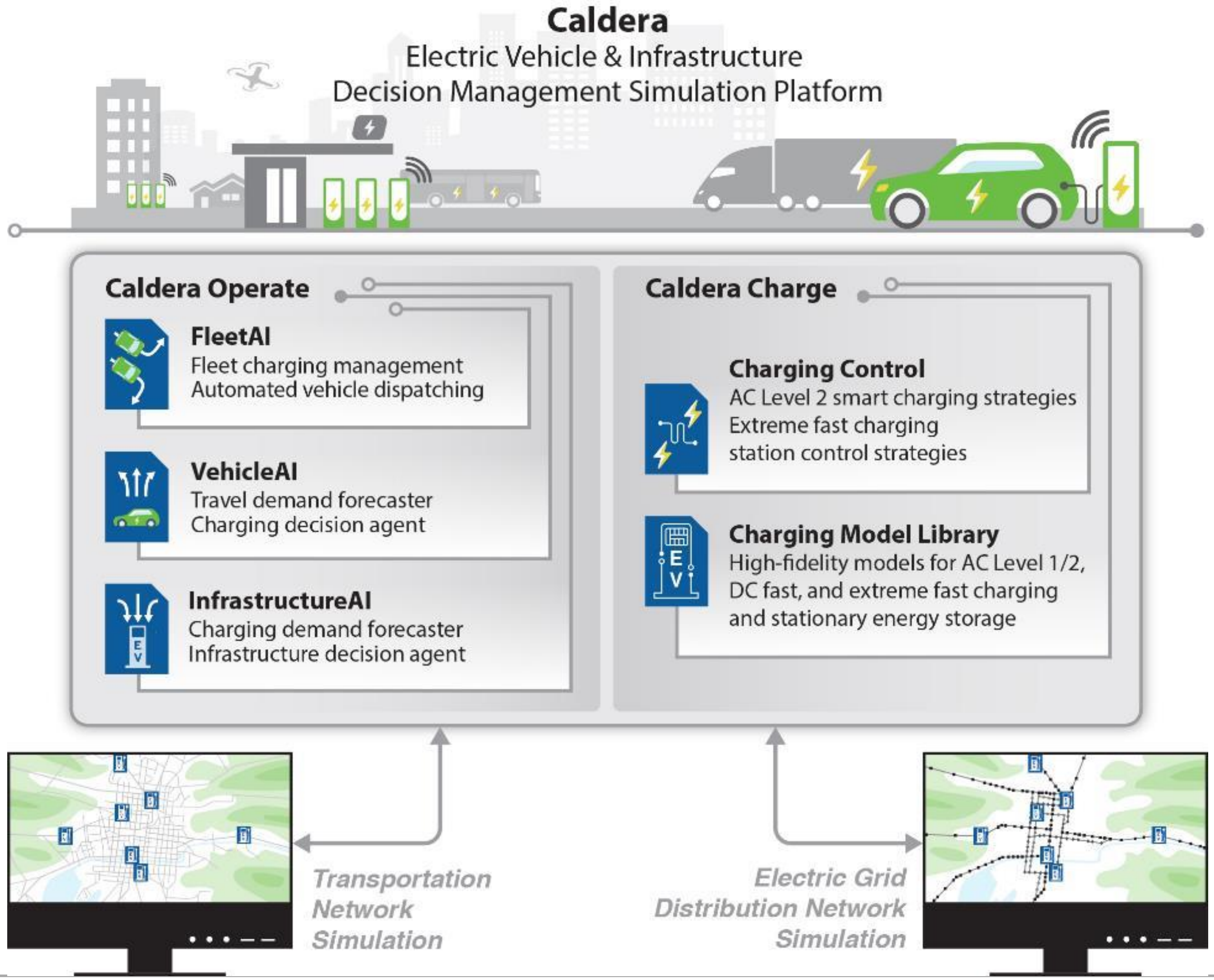
- Cost of EV charging is varied based on status of the grid

RL formulation

- The RL problem has been formulated and implementation on a representative 5-bus system shows promise
- Bus voltage and grid congestion constraints, and cost minimization has been taken into consideration

*The approach is under development. Python-based libraries will be used for the RL agent and MATLAB/OpenDSS for load flow.

INL - EV Modeling for Operations and Charging



https://docs.helics.org/en/latest/user-guide/helics_key_concepts.html

INL's Electric Vehicle Infrastructure Lab (EVIL)

High-power Charging Infrastructure Capabilities

Lab Infrastructure

- 350kW EVSE (ABB TerraHP)
- 50kW EVSE (ABB Terra53)
- Local OCPP 1.6J server

Electric Vehicles enable operation of DC EVSEs

- 400kW charge capable EV emulator (CCS-1)
  - Up to 920V and 500A (400kW power limited)
- 120kW CCS-1 EV
- 50kW CCS-1 EV
- 50kW CHAdeMO EV

ABB

ABB